How can precision livestock farming contribute to the principles of agroecology?

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Livestock farming systems are facing major currents of transitions with growing consideration for agroecology, "One Health and One Welfare" concepts, and increasing integration of digital technologies and sciences. Precision livestock farming technologies can contribute to the pillars of agroecology, for instance through precision feeding to reduce the inputs required for production; sensors and automata can also help to adopt management practices to improve global health and welfare of animals and farmers. Furthermore, digital technologies can help maintain or promote agroecological livestock farming systems through solutions that monitor animals, and facilitate the management and traceability of practices in more extensive systems, such as mountain farming or pastoralism. Therefore, new technologies have the potential to support agroecological transitions, but will not be the driving force behind these transitions. Possible negative externalities, such as environmental impact of digital technologies must also be weighed against their positive internalities for a successful and sustainable integration of digital tools into agroecological livestock farming systems.

Introduction

Agroecology is a scientific discipline and a movement that has been growing since the 2000s. It aims to stimulate natural processes to design agricultural systems that are weakly artificialized, productive, environmentally friendly, and less dependent on chemical inputs (Dumont *et al.*, 2018). Until recently, livestock farming systems have been little considered in agroecology despite the beneficial roles of animals in agroecosystems: producing proteins for humans from inedible resources (*e.g.* grasslands, by-products), providing ecosystemic services (*e.g.* biodiversity) and social benefits, and recycling plant nutrients (Gliessman, 2006). Dumont *et al.* (2013) proposed five principles to extend and apply agroecological concepts to livestock farming systems:

- adopting management practices aiming to improve animal health,
- decreasing the inputs needed for production,

- decreasing pollution by optimizing the metabolic functioning of farming systems,
- enhancing diversity within livestock farming systems to strengthen their resilience,
- and preserving biological diversity in agroecosystems by adapting management practices.

The "One Health/One Welfare" concepts can be integrated with these principles by repositioning the notions of animal health and welfare, respectively, within a holistic approach integrating animals, humans, and their environment, and across scales (local, national, and worldwide). In parallel with the development of these concepts, digital technologies and sciences (sensors, data processing, and transfer, automata, etc.) have been increasingly adapted and integrated into livestock farming systems, mainly intensive, offering new possibilities for monitoring animals and other components of the system as well as for controlling these systems (Faverdin *et al.*, 2020; Ingrand, 2018). Can these developments be integrated into a harmonious common approach? Can digital technologies being adapted to or facilitate the modifications and specificities induced by the application of agroecological principles in livestock farming systems? In the present paper, we first describe examples of contribution of digital technologies to agroecology pillars and One Welfare/One Health concepts in livestock farming systems. Next, we develop the main elements to be taken into account for an effective and responsible use of digital technologies, to maintain and promote agroecological livestock farming systems.

Examples of contribution of precision livestock farming technologies to the pillars of agroecology

This section illustrates how digital technologies can contribute to the integration of the pillars of agroecology and One Health/One Welfare concepts within livestock farming systems. While two application cases are detailed, a summary table (see Table pp. 10-11) lists the possibilities and limits of the contribution of precision livestock farming for each of the pillars of agroecology.

Decreasing the inputs needed for production

Due to the importance of the environmental impact of animal feed production (use of arable land and water…), improving efficiency of feed utilization by animals is a way to reduce the inputs required for animal production (Dumont *et al.*, 2013). In ruminants and pig production, the individual monitoring of performance (growth, milk production, intake) through Radio Frequency IDentification (RFID) technologies, connected weigh scales, milk robots, and automatic feed dispensers allowed the development of precision feeding. This can be defined as an individual and daily adjustment of feed quantity and composition to the nutritional requirements of each individual in a herd, in order to spare feed and nutrient, improve feed efficiency and reduce nutrient excretion. In gestating and lactating sows, the combination of commercial automatic feed dispensers with biological models and data analysis algorithms allows to adapt feed nutrition depending on reproduction performances, feed intake, body composition, and data from previous parities. Experimental application of this method allowed a reduction of around 25% of the lysine ingested without decreasing feed intake, a reduction of 18.5 and 9% nitrogen and phosphorus excretions, respectively, and a decrease of around 4% of feed cost per gestation (so around €3.4 per gestation or €8 per ton of feed) (Gaillard and Dourmad, 2022). The same principles can be applied to growing pigs with expected reduction in nutrient use and excretion.

Table. Application cases of digital technologies as a support for the integration of agroecological principles in livestock production systems: Available possibilities and main limitations.

Agroecological principles	**Possibilities**	**Limitations**
Increasing knowledge dissemination and connections between stakeholders	Mobile applications designed for exchanges between actors of a livestock sector; allowing for a common shared information (*e.g.* on prices or technical figures), organization of the supply chain (collection route, volumes), traceability, and payments (J-D. Cesaro, personal communication). Mobile applications designed for exchanges with the consumers; optical labels (barcodes) can be applied on the products to give information about production processes (*e.g.* grazing), and reinforce the link between the farmer and the consumer. Improved knowledge through easy access to many technical, economic, or environmental resources online.	Inequalities between populations in terms of knowledge, skills, access to technology, technology usability, and maintenance. Loss of knowledge and skills due to the transformation of the farmer as a profession, and the outsourcing of analyses, treatments, and sometimes decisions to digital tools and the associated external contractors.
Preserving biological diversity in agroecosystems by adapting management practices	Decision support tools aiming to preserve and promote virtuous farming practices (grassland, pastoralism), such as rangelands management using GNSS technology to determine grazing routes or directly controlling animal grazing areas with virtual fences.	Technologies can comfort industrial farming practices with little to no direct outdoor connections for the animals. Animal standardization can be promoted through the selection of animals whom format and behavior are compatible with digital tools, such as a milking robot.
Developing smallholders farms	Low-tech developments can provide smallholders farms with dedicated digital tools, and allow for self-maintenance and adjustments of their functionalities based on local needs. They can favor digital uptake and empowerment of rural populations. Reasoning technological needs by identifying and monitoring sentinel or leader animals to detect issues, rather than equipping all the animals within a group.	Livestock farms are frequently located in remote areas with often poor network coverage for data transmission and tool maintenance.

Agroecological principles	**Possibilities**	**Limitations**
Global health and welfare management	Early detection of illness and abnormal behavior helps preventing or diminishing their negative psychological and physiological impacts. Interconnected sensors and dedicated digital tools (based on artificial intelligence) can capture the complexity of a system. They enable an integrated approach to identify and correct the factors causing the disturbance, rather than only intervening on the symptoms caused by the disturbance. Sensors, automates, and digital tools can allow farmers to reduce workload (physical tasks, monitoring time), and bring flexibility.	Unpredictable on-farm events may trigger situations that are outside the operating range of the algorithms, and lead to inappropriate responses. A lack of interoperability between digital tools can trigger false or redundant alarms, increasing work and mental load, and decreasing confidence in digital solutions.
Limiting negative externalities, such as pollution	Precision and smart livestock production systems aim to reason the use of inputs while maintaining productive performances, thus limiting the associated potential pollution.	Digital technologies have negative impacts on the environment from the collection of primary resources, the production process to the waste management and recycling process. The functioning of digital technologies (data transfer and storage) has energy costs and a potential high carbon footprint. False positive alerts can sometimes lead to over medication.

Adopting management practices aiming to improve global health and welfare

Supporting an integrated management of farm animal health requires a knowledge of the local environment as well as on the physiology and behavior of the animals, in order to understand and anticipate their reactions. When considering a set of criteria of different natures, originating and interacting at different scales of the farm, this knowledge can involve high levels of complexity in information processing. Digital tools, based on a combination of various sensors, can be used to improve the acquisition, management, processing, and sharing of this information in order to produce appropriate knowledge and action.

The alerts generated by these tools assist the farmer in their decision-making both in terms of prophylactic and curative treatments, and improve their precision in terms of targets (in the farm environment, on given individuals), quality (type of treatment), and quantity (doses are reasoned). In order to mitigate the effects of the physiopathological expression of the disease, these tools tend to favor predictive alerts whose performances (accuracy, range of application…) are dependent on the quality of the associated algorithms. The type of sensors used will be dependent on the main characteristics of the farming systems and their main health problems. For instance, in small ruminants, the results of the European TechCare project (Giovanetti *et al.*, 2021) show that, for all farming systems, the priority problems are associated with diseases (mainly lameness, mastitis, and dystocia), lack of available colostrum for newborns, and heat stress. For pasture-based systems, specific issues related to undernutrition as well as management of parasite pressure are to be considered. In the same way, for animals raised indoor, housing conditions and competition between animals are complementary factors that need to be considered. To address these issues, a set of measurements from sensor acquisition can be aggregated to provide a comprehensive analysis of animal behavior, and produce early warnings of abnormalities. The production of individual-based measures usually involves embedded sensors, although in some livestock systems fixed sensors may be used for this purpose. This is the case, for example, of machine vision algorithms that analyze images acquired from video recording, to identify the postural features of cattle and pigs that could correspond to early symptoms of illness (Nasirahmadi *et al.*, 2017). In other species, such as poultry, microphones placed in the building can identify abnormal vocalizations, locate their origins, and associate their occurrences with local housing conditions (Du *et al.*, 2018).

All these measures and alerts are likely to improve the health and welfare of animals, by anticipating the appearance of health problems or by detecting them early enough to prevent animals from suffering too long. But improving the welfare of animals can also go through the wellbeing of the farmer. Indeed, the concept of One Welfare recognizes the interdependencies between the welfare of animals and that of humans. For instance, new technologies can allow farmers to save time for automates and sensors replace recurring physical tasks (milking, feeding) while simplifying animal monitoring (reproduction events, health problems). Farmers also appreciate the flexibility to organize their work, and information provided can also lighten the mental load by anticipating events. The time saved allows equipped farmers to spend more time in the middle of the herd, the new information provided by these technologies provides them with more detailed behavioral, physiological or zootechnical knowledge, and the use of sensors and robots generate new relationships that did not exist before (learning to pass through robots, installing collars, ear tags, etc.). However, the mental load can sometimes be increased due to the complexity of the information to be managed, the multiplicity of alarms or alerts, or even the risk of more frequent breakdowns (Hostiou *et al.*, 2017). Finally, for farmers, these new technologies also give a more modern image of their profession, which would make it more attractive (Faverdin *et al.*, 2020).

Digital technologies to maintain or promote agroecological livestock farming systems

Agroecological principles and consumer demands can lead to farming systems that allow more freedom for the animals with, for example, outdoor access for sectors accustomed to mainly indoor farming (pigs, poultry, veal calves). For these livestock systems, the challenge is then to continue to be able to monitor animals with the constraints linked to the distance from the buildings, but also to understand how the change in environment and farming system impacts the herd. More and more studies have been done in the recent years using sensors to better understand how the transition between indoor and outdoor access affects welfare, health, behavior, or growth of animals. Sensors like accelerometers, pedometers, or GPS are then useful to measure the standing/lying position, feeding behaviors, or even use of the outdoor shade (Spigarelli *et al.*, 2020).

Livestock sectors based on more traditional production methods and often already in line with some concepts of agroecology (low inputs, landscape maintenance, protection of biodiversity), such as mountain farming or pastoralism, face the difficulty of finding labor or solutions to monitor and protect their animals, which endangers the maintenance of these farms. Thus, digital technologies make it possible to provide solutions. RFID can be used for the recording of animals at fixed points (drinkers, trough). Positioning units (GPS) mounted on collars can determine animal movements over large areas, determine their habitat, and, somewhat, health and welfare. In combination with other sensors, such units can give information that helps to evaluate the welfare of free-ranging animals. Drones equipped with cameras can also locate and count the animals, as well as herd them. Digitally defined virtual fences can keep animals within a predefined area without the use of physical barriers, relying on acoustic signals and weak electric shocks (Herlin *et al.*, 2021).

Digital technologies can also directly respond to a need of traceability for production practices. For example, in response to consumers' demand, several European dairies have launched so-called pasture milk on the market guaranteeing consumers a minimum number of days of access to pasture for cows. The use of geolocation technologies coupled with artificial intelligence algorithms makes it possible to respond to this request in an automated and secure way (Allain *et al.*, 2020).

Conclusion

New technologies have the potential to support agroecological transitions, but will not be a driver for these transitions. Integrating digital solutions within agroecological livestock farming systems represent a great stake, partly because digital tools can be seen as intrinsically limited in terms of sustainability due to their negative environmental impacts (extraction, waste management, pollution in case of loss…), their resource consumption (electricity for data acquisition and management…), and, over a more or less long period, limited global resources for the raw materials that make up their plastic and electronic components (Pezzuolo *et al.*, 2021). On-farm, they can be used effectively to assist the management inputs of the farmer at various scales (information on the market, continuous monitoring on physiological, health, and behavior processes with associated alerts, waste production…), and with various objectives compatible with agroecology principles (waste management, better animal welfare, nutritional optimization, management of high level of diversity by integrating many aspects of the variations of the system, knowledge sharing…). The integration of digital tools within agroecological livestock farming systems should be considered by taking into account this balance between their positive internalities and negative externalities.

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